IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received September 10, 2019, accepted September 19, 2019, date of publication September 27, 2019, date of current version October 15, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2944135

Capacitated Remanufacturing Inventory Model Considering Backorder: A Case Study of Indonesian Reverse Logistics

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ABSTRACT This paper develops the remanufacturing inventory model considering the storage capacity. The suggested model aims to minimize the total inventory cost (TIC). The model used the EOQ model, one of the basic inventory models in the supply chain. Numerical experiments and sensitivity analyses were carried out on models developed using the Lagrangean method. The existence of constraints in storage capacity can produce an optimal quantity of remanufacturing while minimizing inventory costs. This study also indicates that there is an impact between warehouse capacity, number of cycles, backorder costs, and the level of product collection on total inventory costs, and provides management implications that companies can make appropriate policies to minimize total inventory cost.

INDEX TERMS Backorder, economic order quantity (EOQ), remanufacturing, storage capacity.

I. INTRODUCTION

Remanufacturing activity is one of the advanced processes in reverse logistics activities. Remanufacturing process plays a significant role in the network of reverse logistics as the same with the importance of manufacturing activities in the forward logistics network. It is the same as remanufacturing which aims to restore product functionality as before as new products so that the manufacturing industry no longer takes 100% of its raw material needs from nature but can utilize products that have expired to be reprocessed into similar products [1].

Some literature discusses the positive aspects of the remanufacturing process in the reverse logistics network because in the process of remanufacturing does not require raw material in producing products as the case in conventional network logistics. For companies that also have a conventional logistics network, the results of the remanufacturing process can immediately follow the next existing process, for example, the results of remanufacturing products could be distributed in the existing process of distribution or stored in the existing warehouses. The remanufacturing process has numerous benefits savings in labor, material and energy costs. it can also reduce environmental impacts and reduce disposal costs [2], [3].

For some cases of products that need remanufacturing the process, often the process of remanufacturing a product occurs using lot-sizing or batching processes, where the process of remanufacturing new products is carried out if the number of products to be remanufactured has reached a certain amount. It is done so that the optimal remanufacturing process is achieved even though there is a risk of increasing inventory costs. Some research has discussed and developed the remanufacturing network model by considering optimal inventory (remanufacturing inventory model), for example, Richter [4] developed the EOQ model for production and remanufacturing, then Jaber and El Saadany [5] modeled production inventories and remanufacturing models by considering lost sales due to the occurrence of stock-outs. Also, Hasanov *et al.* [6] who tried to model remanufacturing networks by considering full and partial backorder show that the results of remanufacturing cannot meet customer requirements by the amount and time required due to unavailability of enough storage capacity.

Modeling remanufacturing networks that consider inventory levels will be closely related to the capacity of storage

The associate editor coordinating the review of this manuscript and approving it for publication was Nikhil Padhi.

or warehouse. The limitation of storage would affect the inventory model which ultimately affects the remanufacturing model [7]–[9]. Previous research by Hasanov *et al.* [6] modeled production supplies and remanufacturing processes by applying full and partial backorder to meet consumer demand indicating that the need for storage capacity is very important in making remanufacturing models related to the amount and cost of inventory. Slightly different from previous research, this time the research focused on the latest issues regarding remanufacturing model taking into account storage capacity. Therefore, this article integrates inventory models in remanufacturing networks by considering the capacity constraints of storage to minimize the total cost of remanufacturing.

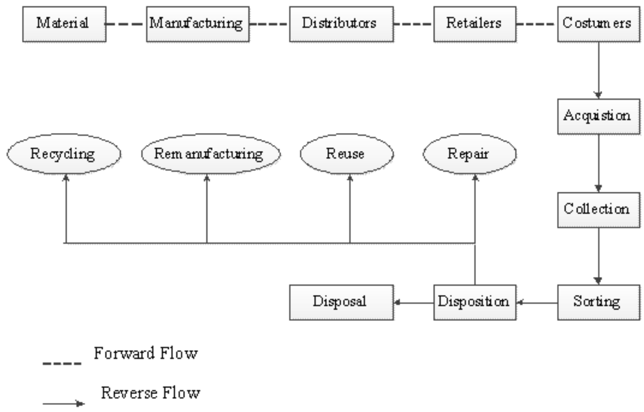

FIGURE 1. Flows of forwarding and reverse logistics.

II. LITERATURE REVIEW

A. REMANUFACTURING PROCESS IN REVERSE LOGISTIC

Reverse logistics is all activities that include planning, processing, reducing, disposing of hazardous or non-hazardous waste from the production, packaging, and use of products. Because of the opposite flow of goods from the flow in conventional supply chains, reverse logistics is often also called "backward logistics", where the flow of goods flows backward from consumers to retailers and from producers to suppliers [10], [11]. Reverse logistics deals with all flows of goods and information that are important for collecting product use, material packaging, production cancellations, and others. Then it is brought to a place where it can be reused, reproduced, recycled or destroyed [12]. The main purpose of reverse logistics is to return and provide the same functions and values as before for used products returned. One such activity is remanufacturing, where this process aims to restore the function of the product as before, like a new product so that the manufacturing industry is no longer taking raw materials from nature in full, but can use products that have expired and are reprocessed to become similar products [13].

The main focus of remanufacturing activities on reverse logistics is to restore the quality of returned products to new ones [14] There are many reasons for companies to carry out remanufacturing systems in their companies, including environmental reasons regarding product returns to protect the environment, and reasons for waste occurring in the community [15]. The company will compete in reducing the environmental impact by returning and reprocessing returned products to become new products. Also, by returning this product, the company can save the use of natural resources because raw materials can be replaced with used products that can be reprocessed into new products [15].

Manufacturers usually prepare certain supply chain networks in managing returned products, for example, rental facilities such as dealers, collectors or third parties to collect products from customers before returning them to the factory. This long process will certainly require time, costs for returning goods such as transportation costs, or the cost of shipping goods from collectors or third parties [16].

Forward and backward logistics flow from Figure 1 shows that forward logistics starts from raw materials from suppliers and ends at the end product at end customer, whereas reverse logistics starts from end customers to the collection point for used goods to make efforts to repair, reuse, remanufacture, recycle and redistribute it as a new product.

Reverse logistics is an issue that is concerned in environmental studies, because of the manufacturing process, in particular, the negative impact of hazardous material on all parties in the supply chain, if managed inappropriately. Proper reverse logistics management can be categorized into four types, namely repairing, recycling, remanufacturing, and reuse. The main problem faced by the manufacturing industry in implementing recycling systems is the low recovery value and requires a high investment in providing large quantities of products or materials. Therefore, a closed-loop supply chain on a small level structure is required. A closed-loop supply chain is a system that starts from returning or shipping used products to the manufacturer for reprocessing. The processing of used products is divided into two, namely remanufacturing and refurbishing. Remanufacturing is the process of processing used products into products of the same quality as new products so that they can be sold at the same price [17]. Used products must meet the criteria for reprocessing, the product is then sent to the producer through a collector. While the process of processing used products into products of lower quality than new products is called refurbishing. Repair products are sold at lower prices than new products.

Implementing an effective reverse logistics system could reduce costs, increase revenue, and even maintain customer loyalty and protect corporate brands [18]. Also, compliance with regulations to protect the environment, including reducing the consumption of natural resources through recycling and other forms of product recovery has increased the need for effective reverse logistics [19]. These economic and environmental motivations have encouraged researchers to develop models to study and analyze inventory flows in reverse logistics.

B. CONCEPT OF INVENTORY MANAGEMENT IN REMANUFACTURING SYSTEMS

The remanufacturing process is the return of condition and performance of used products into new goods and guaranteed products such as new product [13]. The remanufacturing process can reduce the natural resources needed to make a product and can reduce energy consumption due to a reduction in work processes. The remaining amount of work produced by the manufacturing process can also be reduced because used goods are reused. Some of the advantages mentioned above make the remanufacturing process provide many benefits both financially and environmentally [20].

Managing inventories for processes that involve collecting used goods, recovering them, and producing new goods are as important as the items from the forward chain [21]. Inventory models that handle product backflow have two main constraints. First, collected used goods are restored to their original conditions or with acceptable quality [22]. Second, the number of times items that can be recovered is unlimited [5].

The remanufacturing system is further developed which assumes that customer demand can be met by a stock of items that can be repaired (produced and reproduced). In general, customers do not consider goods that are newly produced and goods that are reproduced (repaired) as items that can be exchanged. Remanufactured goods are sold at lower price points in the secondary market, or in various new product channels that are sold in the primary market [23]. Other previous studies by Jaber and El Saadany [5] resulted in a lost sales situation when there was a period of out of stock for goods produced and reproduced. In other words, the demand for newly produced goods disappears during the remanufacturing cycle and vice versa.

TABLE 1. Previous literature regarding inventory with remanufacturing processes.

Author	Model		Constraint				
	EOQ	POQ	Backorder	Setup cost	Stockout	Lost sale	Leadtime
Richter [27]	✓						
Richter [4]	✓			✓			
Dobos and Richter [28]	✓						
Teunter [12]	✓	✓					
Tang and Grubbström [29]							✓
Konstantaras and Papachristos [26]	✓		✓				
Jaber and El Saadany [5]	✓					✓	
Rubio and Corominas [22]	✓	✓					
El Saadany and Jaber [30]	✓	✓					
Flapper, et al. [31]			✓		✓		
Liao and Deng [32]	✓						
Kilic and Tunc [33]			✓				

C. REMANUFACTURING SYSTEM WITH BACKORDER

In today's competitive market competition, companies do everything possible to not lose their customers to competitors by increasing their level of service. One option is to allow reverse orders, where some customers are compensated to wait for their pending orders either with price reductions or some other form of discount, which is the cost incurred by the supplier company. This results in backorder costs which are usually higher than inventory storage costs [24]. However, there are situations where some customers do not want to wait for their orders and leave the system [25]. This is what makes the company makes policy regarding the waiting system or what is called backorder. The inventory model with a backorder is indicated by receipt of orders from customers will still be accepted even though at that time there is no inventory.

A study by Hasanov *et al.* [6] describe the inventory model by considering backorder in two situations, namely full back-ordering problems and partial back ordering problems. Konstantaras and Papachristos [26] expanded the model of remanufacturing inventory problem by enabling planned backorder in remanufacturing and production while keeping other assumptions the same; in particular, recovered items are as good as new ones. Furthermore, Jaber and El Saadany [5] developed a remanufacturing inventory model for the case of full-backorder and partial-backorder, in which the recovery of goods (reproduced or repaired) is considered by the customer to have lower-quality; that is, not as good as the new one. Furthermore, this paper considers additional cases where the reorder period is shortened. In their research, the term of remanufacturing is used to refer to used goods collected and recovered, while the term produced is used to refer to goods produced from 'new' materials and components.

Previous studies discussed the remanufactured inventory model with various limits with backorder, set up costs, out stock, lost sale, and lead time shown in Table 1.

Remanufactured inventory model including Richter [27] in his research, was developing a model of improvement/disposal of inventory where stationary demand can be met by items newly produced and repaired. Furthermore, Richter [4] extends the results of previous studies to provide

TABLE 2. Previous literature regarding capacitated and uncapacitated storage remanufacturing models.

Author	Capacitated	Uncapacitated	Approach
Teunter, et al. [34]		✓	Silver Meal (SM), Least Unit Cost (LUC) and Part Period Balancing (PPB) heuristics.
Pan, et al. [8]	✓		Dynamic programming algorithms, and A pseudo-polynomial algorithm.
Pineyro and Viera [35]		✓	Tabu-Search.
Wang, et al. [36]		✓	EOQ.
[6]		✓	EOQ.
Bulmuş, et al. [2]	✓		A mathematical model with Q.
Roshani, et al. [9]	✓		Annealing Algorithm.
Cunha, et al. [37]		✓	Mathematical model (EOQ).
Marshall and Archibald [38]		✓	Mathematical model (EOQ).
Ali, et al. [39]		✓	Integer programming
Cunha, et al. [7]	✓		Linear Programming (LP) / MIP. Metaheuristic.

further interpretation, namely by adding set up costs to economic aspects. In subsequent studies, Dobos and Richter [28] developed similar models, but with different assumptions. Different from previous research Teunter [12] developed two models as well as the problem of remanufacturing, namely comparing the optimal lot of POQ and EOQ to minimize the total cost of inventory.

Following is the previous literature which shows a comparison of research on the model of remanufacturing with capacitated and uncapacitated storage.

The optimal inventory level is a matter that must be considered in the procurement of raw materials. To determine the size of the order, inventory control calculations are carried out by considering the constraints of warehouse capacity using the development model of the inventory model. Hasanov *et al.* [6] in his research developed a remanufacturing inventory model, but assuming that capacity is unlimited. Moreover, Cunha *et al.* [37] consider the problem of lot-sizing multi-item economics with non-capacity remanufacturing and production. The development of further research by Bulmuş *et al.* [2] who are inspired by the situation for certain car companies. Then analyze the two-period model with manufacturing in the second period, and for remanufacturing products that are returned/collected at the end of the first period. In his research, the optimal number of manufacturing and remanufacturing was obtained and analyzed under conditions determined by costs, capacity restrictions, and demand.

III. MODEL DEVELOPMENT

The remanufacturing system developed into a remanufacturing inventory problem this study can be seen in Figure 2:

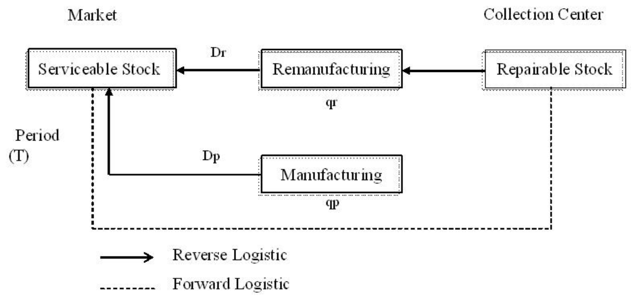

FIGURE 2. Remanufacturing inventory network.

The remanufacturing system described in Figure 2 consists of two stores. Items that are reproduced (repaired) as much as demand (Dr) and produced (Dp) are stored in the first store (stock that can be repaired), while used goods are stored in the second store (repairable stock). The collected used items are filtered, and items that are considered irreparable are disposed of at the stage before the stock can be repaired. It also assumed that there is recycling (m) and the production cycle in intervals of time (T). The goods produced are not stored above the remanufacturing segment (Tr) of T. Likewise, the goods that are reproduced are not stocked above the production segment (Tp) of T. This results in the loss of the sales situation during Tr. In a competitive market, companies tend to succeed in increasing service levels for their products by attracting customers to wait for their orders when a deposit guarantee situation occurs.

This study assumes remanufacturing batches (m) of each size (qr) and (n) production batches of each size (qp) at T, where many remanufacturing units (mqr) are consumed in full above interval of time (Tr), while many units (nqr) fully consumed in excess of Tp. The assumption is that unmet demand for remanufacturing and production is complete, then the limit occurs at the optimal number of lots (qr) limited by warehouse capacity.

A. MATHEMATICAL MODEL

In this study, the inventory model from Hasanov *et al.* [6] is expanded considering warehouse capacity limits. The model is solved by the Lagrangean multiplier approach. In this study, calculating costs in the developed model of capacitated remanufacturing inventory model (CRIM), fully backorder is applied as unsatisfied demands of remanufactured and produced processes are occurring. The total cost per cycle (interval) for this case is the sum of the setup costs for remanufacturing and production batches, back-ordering costs for the remanufactured and produced items, the holding cost for items in the serviceable stock, and the holding cost for items in the repairable stock. As illustrated in Figure 3, customers wait until the arrival of the next replenishment

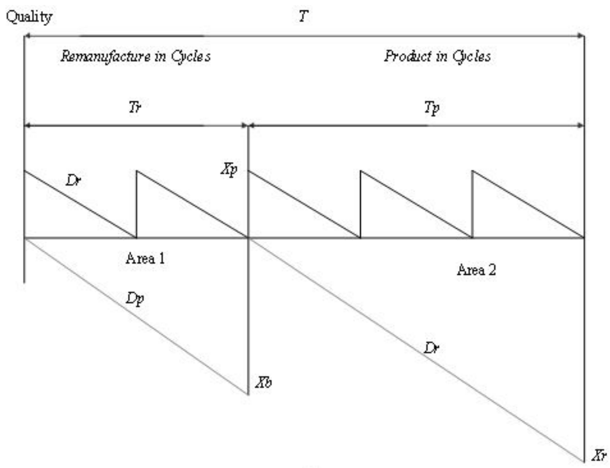

FIGURE 3. **The behavior of inventory remanufacturing and manufacturing with a pure backorder.**

(remanufacturing or production) before receiving their backlogged orders. Area 1 dan Area 2 represents the backlogged quantities accumulated over the remanufacturing and production segments of T, respectively, where the quantities of xbp an xbr represent the maximum backorder levels for produced and remanufactured items by the end of each corresponding segment of T.

The total backorder cost for production in the remanufacturing period (Area 1) is:

$$BCp\frac{xb}{2}Tr = \left(BCp\left(\frac{mqr}{Dr}\right)\right)^2\frac{Dp}{2} \tag{1.1}$$

where, $Tr = \frac{mqr}{Dr}$ *and* $Xb = TrDr$ similarly, from area 2 we have:

$$BCr\frac{Xr}{2}Tp = \left(BCr\left(\frac{nqp}{Dp}\right)\right)^2\frac{Dr}{2} \tag{1.2}$$

Mqr is the lot size quantity (in units) to be remanufactured in T, which is mqr= $\gamma r\beta r+\ \gamma p\beta p\ nqp\ \gamma r\beta r + \gamma p\beta pnqp$ unit. Accordingly:

$$\frac{qp}{qr} = \frac{m(-\beta r\gamma r + 1)}{n\gamma p\beta p} \tag{1.3}$$

Substituting Eq (1.3) in Eq (1,2) and adding the result to Eq (1.1) the total back-ordering cost in interval T is given as:

$$\begin{aligned} BCrp(n,\gamma r,\gamma p) = BCp\left(\frac{mqr}{Dr}\right)^2\frac{Dp}{2} \\ +BCr\left(\frac{nqr}{Dp}\right)^2\left(\frac{m}{n}\frac{(\beta r\gamma r)}{\beta p\gamma p}\right)^2 \end{aligned} \tag{1.4}$$

Then, the total holding cost is the sum of holding costs for remanufacturing + holding costs for production + holding costs for products used,

$$\begin{aligned} H\,(n,m,\gamma r,\ \gamma p) &= \left(hr\frac{m}{2Dr}\right) \\ &+\left(hp\frac{n}{2Dp}\right)\left(\left(\frac{m}{n}\right)\frac{1-\gamma r\beta r}{\gamma p\beta p}\right)^2 \\ &+hu\left[\left\{\frac{m\,(\gamma r\beta r-1)}{2Dr}\right\}m + \frac{\gamma p\beta pm^2}{2Dp}\left(\frac{1-\gamma r\beta r}{\gamma p\beta p}\right)^2\right. \\ &\left.+m\left(\frac{\gamma r\beta r}{Dp}+\frac{\gamma p\beta p\,(m-1)}{Dr}\right)\left(\frac{1-\gamma r\beta r}{\gamma p\beta p}\right)\right] \end{aligned} \tag{1.5}$$

The total cost per interval T is the sum of the total setup cost per cycle, total holding cost per cycle, and total back-ordering cost per cycle. The total cost per unit of time is given by dividing the sum by T as:

$$\omega(n,m,\gamma r,\gamma p) = \frac{A(Hqr^2 + qr^2BCrp + Spn + Srm)}{qr} \tag{1.6}$$

Which $A = \frac{1}{T}$ is, after setting the first derivative of Eq (1.6) equal to zero and solving for qr we get:

$$\begin{aligned} &qr\,(n,m,\ \gamma r,\ \gamma p) \\ &= \sqrt{\frac{mSr + nSp}{H\,(n,m,\ \gamma r,\ \gamma p) + BCrp\,(m,\ \gamma r,\ \gamma p)}} \end{aligned} \tag{1.7}$$

Substituting Eq (1.7) in Eq. (1.6) we get:

$$\begin{aligned} &\omega(n,m,\gamma r,\gamma p) \\ &= 2A\sqrt{(mSr+nSp)H(n,m,\gamma r,\gamma p)+BCrp(m,\gamma r,\gamma p)} \\ &z = minimize\omega(n,m,\gamma r,\gamma p) \end{aligned} \tag{1.8}$$

Subject to: n.m $\geq$ 1, integer

$$0 \leq \gamma r \leq 1,$$
$$r_{min} \leq \gamma p \leq 1,$$
$$r_{min} > 0$$

B. DEVELOPING MODEL OF CAPACITATED REMANUFACTURING INVENTORY PROBLEM

This study develops a remanufacturing inventory model of Hasanov *et al.* [6] with backorder by considering storage capacity limits. The storage boundary in question is the storage capacity owned by the company. So, lot order quantity is not permitted to exceed the available warehouse capacity limit. It is also necessary to review the use of space per unit of raw material to suit the available capacity. By using the Lagrange function, the model formulation is obtained as follows, with conditions;

F $\geq$ o$*$qr
F: storage capacity
o: Space usage per unit

The largest inventory volume that can be stored is equal to the available capacity. Thus the limited use of warehouses must be a limitation to minimize total inventory costs. mathematically, solved by optimization problems, e.g: (1.4)

$$min\frac{A(Hqr^2 + qr^2BCrp + Spn + Srm)}{qr}$$

Against the constraint function:

qr ∗ O ≤ F

where qr ≥ 0.

The problem was solved with the approach of Lagrangean Multiplier. In this case, o∗qr = F is used because the Lagrangean method can only be used to solve optimization with equation constraints. Then F is interpreted as a maximum value that does not exceed o∗qr or qr – F = 0

$$L(Q,\lambda) = \frac{A(Hqr^2 + qr^2BCrp + Spn + Srm)}{qr} + \lambda oqr - \lambda F \tag{1.9}$$

Furthermore, minimized against qr, it can be obtained an optimal qr value by entering the storage capacity as a constraint.

$$\frac{dL}{dqr} = \frac{A(2Hqr + 2qrBCrp)}{qr} - \frac{A\left(Hqr^2 + qr^2BCrp + Spn + Srm\right)}{qr^2} + \lambda o$$

$$\frac{dL}{dqr} = \frac{AHqr^2 + Aqr^2BCrp - ASpn - ASrm + oqr^2\lambda}{qr^2} \times \frac{dL}{dqr} = 0$$

$$\frac{AHqr^2 + Aqr^2BCrp - ASpn - ASrm + oqr^2\lambda}{qr^2} = 0$$

$$Hqr^2 + Aqr^2BCrp - ASpn - ASrm + oqr^2\lambda = qr^2$$

$$r = \frac{\sqrt{AH + ABCrp + o\lambda}\sqrt{ASpn + ASrm}}{AH + ABCrp + o\lambda}$$

$$r = \frac{\sqrt{A}\sqrt{Spn + ASrm}}{\sqrt{AH + ABCrp + o\lambda}} \tag{1.10}$$

Then, it is minimized to the value of λso that the equation for the boundary or lambda value is obtained as follows:

$$\frac{dL}{d\lambda} = \frac{A(Hqr^2 + qr^2BCrp + Spn + Srm)}{qr} + \lambda oqr - \lambda F \frac{dL}{d\lambda} = oq - F$$

$$\frac{dL}{d\lambda} = 0$$

Then $oq - F$

$$qr = \frac{F}{o} \tag{1.11}$$

The actual role of lambda is not very significant, but lambda serves to determine valid model indicators to use. When there are no warehouse constraints and the warehouse capacity of equation (1.10) cannot be used, in other words, the limitations of the storage become the dominant factor to determine the optimal qr number, so lambda can also be calculated with the following equation:

$$\lambda = -\frac{A(-Spno^2 - Srmo^2 + F^2H + F^2BCrp)}{F^2o} \tag{1.12}$$

Notations:

m = number of remanufacturing cycles in interval T
n = number of production cycles in interval T
γr = collection percentage of available returns of previously remanufactured items ($0 < \gamma r \leq 1$)
γp = collection percentage of available returns of previously produced items ($0 < \gamma p \leq 1$)
θr = proportion of a batch of used/repaired items consumed in the remanufacturing segment T ($0 < \theta r < 1$)
θp = proportion of a batch of new-produced items consumed in the production segment of T ($0 < \theta p < 1$)
Dr = demand rate for remanufactured items (units/unit of time)
Dp = demand rate for produced items (units/unit of time)
Sr = set up cost per remanufacturing batch ($)
Sp = set up cost per production batch ($)
LCr = lost sale cost for a remanufactured item ($ / unit)
LCp = lost sale cost for a produced item ($ / unit)
BCr = backorder cost for a remanufactured item ($ / unit / unit of time)
BCp = backorder cost for a produced item ($/unit/unit of time)
hr = holding cost for a remanufactured item ($/unit/unit of time)
hp = holding cost for a produced item ($/unit/unit of time)
hu = holding cost of a used items ($/unit/unit of time)
βp = percentage of available returns from the primary market for produced items
βr = percentage of available returns from the secondary market for remanufactured items ($0 < \beta r \leq \beta p < 1$)
s = proportion of Dp that is backordered $0 < s < 1$ where (1 – s) is the proportion of Dp that is lost
v = proportion of Dr that is backordered $0 < v < 1$, and (1 – v) proportion of Dr that is lost
qp = production *batch size*
qr = remanufacturing *batch size*
Tr = length of a remanufacture segment
Tp = length of a production segment
T = length of the time interval ($T = Tr + Tp$)
T_r^r = stock-out period for produced items in segment Tr $Tr(T_r^r = Tr - T_r^p)$
T_p^p = stock-out period for remanufactured items in segment Tp $(T_p^p = Tp-)$
T_r^p = length of the period for which the inventory of produced items is positive in $Tr(T_r^p = \frac{qp}{D_p} - tp)$
T_p^r = length of the period for which the inventory of remanufactured items is positive in Tr $(tr = \theta r \frac{q_r}{D_r})$
tr = length of an incomplete remanufacturing cycle in segment Tr $(tr = \theta r \frac{q_r}{D_r})$

tp = length of an incomplete production cycle in segment Tp ($tp = \theta p \frac{q_p}{D_p}$)
x_p^b = maximum back-ordering level for produced items in T
x_l^b = maximum back-ordering level for remanufactured items in T
x_p^l = units loss of produced items in T
x_r^l = units loss of remanufactured items in T

IV. RESULTS AND DISCUSSION

A. INFLUENCE OF CAPACITY (F)

Numerical experiments are carried out by planning product orders with a total demand Dp=1.048. hp=22, hr= 17, m=2, n=4, $(\gamma r) = 0,25\,(\gamma p) = 0,35$, Sp= 852.253, Sr=576.127. The use of the room every single unit product o=0.181 m^3. And consider the parameter $\beta p = \gamma p, \beta r = \gamma r$. The values of the input parameters that are specific to the model developed in the paper. Where to use the different storage capacities in the 10 experiments performed. In this case, it will be calculated the amount of the quantity remanufactured (qr), the total cost of inventory (TIC) in the two situations: with and without storage limitation.

Table 3 shows that the quantity number of the remanufactured model with the storage capacity in consideration is 110 units. The number of remanufacturing quantity adjusts to the available capacity constraints and the use of the room per one product unit. Reviewed from Table 3, the result of the qr is 5 times greater than the storage capacity. Because the consumption of the room per unit of product is 0.181 m^3, while the optimal quantity calculation (qr) is the capacity of the storage divided by the consumption of the room per unit product. Moreover, if the storage capacity available is relatively small, then the lot size remanufactured relatively little. If the available storage capacity is relatively large, then the lot size is relatively much.

TABLE 3. Experiments with the storage capacity.

Storage capacity (m^3)	Quantity of remanufacturing (unit)	Holding cost ($)	TIC ($)	λ	The optimal quantity of remanufacturing (unit)	TIC ($)
5				1.56	27	8,732
10				317	55	5,078
12				191	66	4,580
16				66.2	88	4,100
20	110	336	3,965	8	110	3,965
24				-23	132	3,998
26				-33	143	4,054
28				-42	154	4,129
30				-49	165	4,220
35				-61	192	4,490

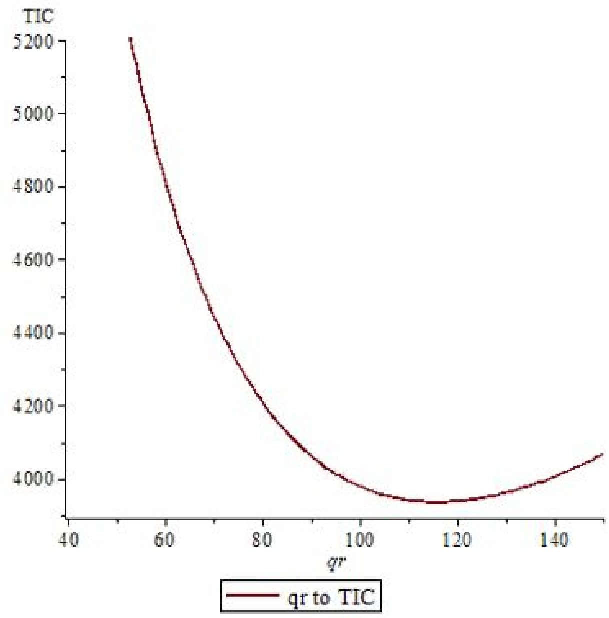

FIGURE 4. The optimal quantity based on storage capacity.

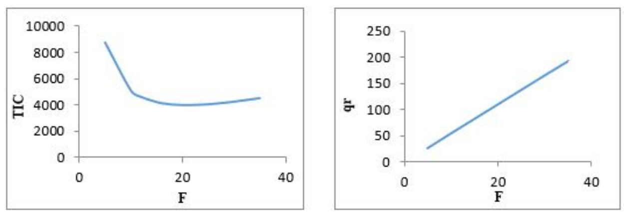

FIGURE 5. Influence of capacity for total cost and quantity of remanufacturing.

Based on the analysis that has been done, if the limit value or lambda > 0, then used equation (11) or qr that considers the warehouse capacity limitation, because the result of the remanufactured quantity to be done does not exceed the available storage capacity limitation. When the limit value or lambda is < 0, the equation is used (6) or the initial qr. It is also reviewed from the results the quantity of remanufactured that has been followed by the available storage capacities. The following figures also indicate that the smaller the storage capacity, the greater the total cost of inventory needed. Similarly, if the available storage capacity is getting bigger then the total cost of the inventory is smaller. But the total cost is minimal when the quantity is optimal.

B. INFLUENCE OF NUMBER OF cycles

Experimental results can be compared in Tables 4 and 5 by experimenting on cycles. Table 4 is done by making trial errors in the remanufacturing cycle, while the manufacturing cycle is fixed n = 2. It appears that the size of the cycle is directly proportional to the number of lots reproduced, as well as the total costs incurred. This is because the more frequent remanufacturing of the number of lots stored will be more, resulting in greater savings and higher total costs. This condition can be seen in Table 4.

TABLE 4. Experiment with the number of remanufactured cycles.

Number of remanufacturing cycle	Holding cost ($)	Quantity of remanufacturing (unit)	TIC ($)
1	3.6	81	2,786
2	7.4	91	3,135
3	11.2	99	3,456
4	15.1	106	3,755
5	19.2	113	4,039
6	23.38	119	4,301
7	27.6	125	4,571
8	31.9	130	4,824
9	36.4	135	5,070
10	41	140	5,310

TABLE 5. Experiment with the number of manufactured cycle.

Number of the manufacturing cycle	Holding Cost ($)	Quantity of Remanufacture (unit)	TIC$
1	7.6	76	2,627
2	7.4	91	3,135
3	7.3	103	3,572
4	7.2	115	3,960
5	7.2	125	4,314
6	7.2	134	4,642
7	7.2	143	4,947
8	7.2	152	5,235
9	7.2	160	5,508
10	7.1	167	5,767

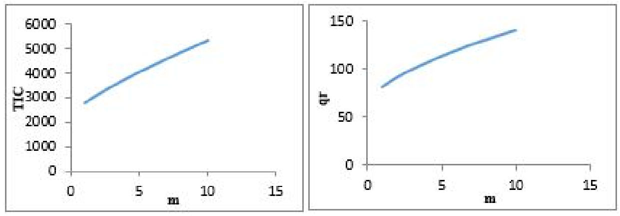

FIGURE 6. Influence of remanufactured cycles against remanufactured quantity and total cost.

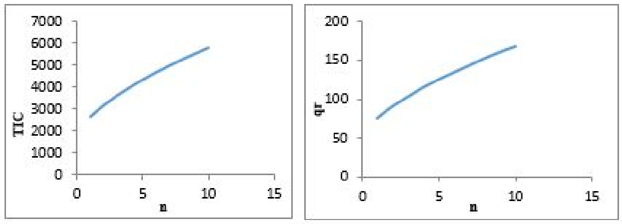

FIGURE 7. Influence of manufactured cycles against remanufactured quantity and total cost.

TABLE 6. Experiments with the remanufactured product collection rate.

The remanufactured product collection rate	Holding cost ($)	Quantity of remanufacturing (unit)	TIC ($)
90%	1.2	116	3,926
80%	1.4	116	3,927
70%	1.6	116	3,928
60%	1.8	116	3,929
50%	2	116	3,930
40%	2.2	116	3,931
30%	2.4	115	3,933
20%	2.6	115	3,934
10%	2.8	115	3,935
0	3	115	3,936

The next simulation is done by making a trial error in the manufacturing cycle while the remanufacturing cycle remains at m = 2 and its effect on the remanufacturing lot as well as the total cost.

Based on the simulations carried out in Table 5 after numerical experiments on the number of manufacturing cycles in a period, it appears that a large number of cycles will affect store costs and total costs. The more cycles that occur, the greater the total costs will be, as well as the more quantities that are reproduced. The size of the cycle is directly proportional to the number of lots produced and the total cost. The test results of Figure 6 and 7 can be compared, where it appears that when the manufacturing cycle (n) is greater than the remanufacturing cycle (m), the savings costs and total costs incurred will also be greater, than when the manufacturing cycle (m) is greater than manufacturing cycle (n). This also affects the total costs incurred. The manufacturing cycle further influences the cost increase compared to the manufacturing cycle.

C. INFLUENCE OF PRODUCT COLLECTION RATE

Further experiments to determine the effect of the level of product collection on the total cost and quantity of remanufacturing, the parameter values used for several numerical examples are the same as before, the percentage of collection of remanufactured products, and the percentage of collection of different manufactured products in 10 experiments carried out. In this experiment, the amount of re-produced lots (qr) is calculated, the total inventory cost (TIC). Furthermore, by experimenting with making a trial error on the rate of return of remanufactured products (γr) while the rate of return of manufactured products remains γp = 1 and its effect on remanufacturing lots and total costs. Then, experiment by making a trial error on the return of a manufactured product (γp) while the remanufactured product collection rate remains anr = 1 and its effect on qr and TIC.

Based on 10 experiments that have been carried out at the level of collection of remanufactured products in one period, it is shown that product collection does not significantly affect

TABLE 7. Experiments with the manufactured product collection rate.

The manufactured product collection rate	Holding cost ($)	Quantity of remanufacturing (unit)	TIC ($)
90%	1.1	116	3,925
80%	1.2	116	3,926
70%	1.4	116	3,927
60%	1.6	116	3,928
50%	2	116	3,930
40%	2.5	115	3,933
30%	3.3	115	3,938
20%	5	115	3,948
10%	10.2	114	3,978
0	0	0	0

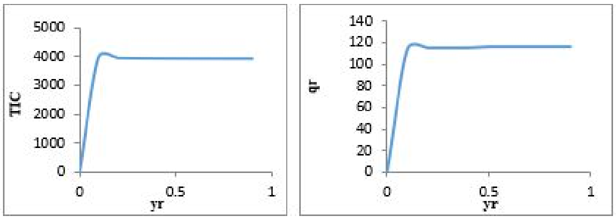

FIGURE 8. Effect of remanufacturing product collection against remanufacturing quantity and total cost.

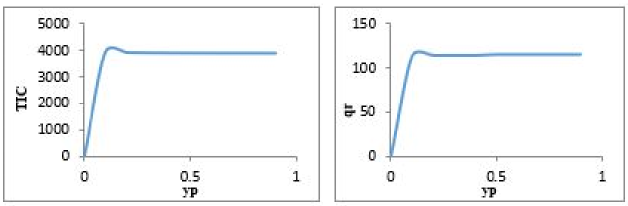

FIGURE 9. Effect of manufacturing product collection against remanufacturing quantity and total cost.

the total quantity and total costs; however, increasing store costs will reduce total costs.

Table 7 also shows that high manufacturing product returns (γp), storage costs will be lower. The level of γp increase in Table 6 is not much different from Table 7, but the return of manufactured products further affects the cost of savings, because it does not allow 0, and low γp will have an impact on the large level of cost savings.

D. INFLUENCE OF BACKORDER COST

In the previous trial, there was no change in the reorder fee, the next attempt by conducting a numerical trial on the reorder (re-order) cost was different in 10 attempts. In this experiment, we will calculate the number of re-produced lots (QR), the total inventory cost (TIC), and the variable costs that affect it as the BCr = 5.

Based on experiments that have been done in Table 8, trial and error on remanufactured backorder cost in one period affects the remanufactured lot and total cost. The larger the BCr the lower the lot size and the greater the total cost

TABLE 8. Experiments with the back-ordering cost of manufacturing products.

Back-ordering cost of manufacturing products ($)	Total of backorder cost ($)	Quantity of remanufacturing (unit)	TIC ($)
1	390	107	4,256
2	472.5	97	4,678
3	610	85	5,306
4	802.5	75	6,077
5	1,050	65	6,944
6	1,352	57	7,876
7	1,710	51	8,850
8	2,122	46	9,856
9	2,590	41	10,886
10	3,112	38	11,929

TABLE 9. Experiments with Bacordering cost of remanufacturing products.

Back-ordering cost of remanufacturing products ($)	Total of backorder cost ($)	Quantity of remanufacturing (unit)	TIC ($)
1	702	80	5,687
2	745.5	77	5,860
3	818	74	6,135
4	919.5	70	6,501
5	1,050	65	6,944
6	1,209.5	61	7,449
7	1,398	56	8,007
8	1,615.5	53	8,603
9	1,862	49	9,234
10	2,137.5	46	9,890

incurred. It is then attempted to raise the BCr against the QR and the total cost when BCp = 5.

Table 9 shows that increasing the amount of BCp affects the amount produced and the total cost. The greater the BCp, the lower the lot size and the greater the total costs incurred. It seems that the high cost of re-ordering manufactured products has more effect on the higher total order costs than the cost of re-ordering products.

E. MANAGEMENT IMPLICATIONS

Some considerations can be taken by the company from the results of experiments that have been conducted which show the impact of the capacity storage on the total costs incurred. The smaller the storage capacity, the total cost will increase significantly. In this case, the company can consider increasing storage capacity not only to accommodate more products but also to minimize the total inventory costs incurred. For more details can be seen in Figure 5, the effect of storage capacity on total costs.

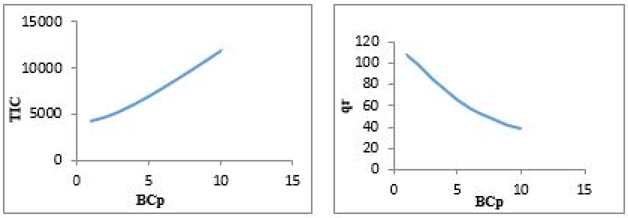

FIGURE 10. Influence of backorder costs against remanufactured quantities and total costs.

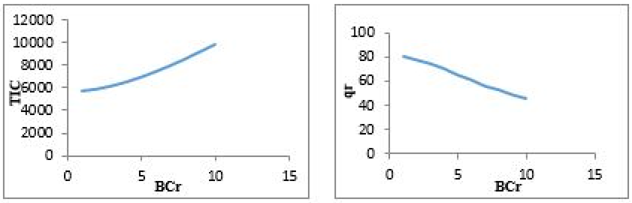

FIGURE 11. Influence of backorder costs against remanufactured quantities and total costs.

It is previously discussed that the number of cycles that occur affect the cost of storage, and the total cost. In the previous research model, increasing the number of remanufacturing cycles would increase storage costs but do not see a comparison of total costs. Figure 6 and Figure 7 have compared the number of remanufacturing cycles with the total cost and lots of remanufacturing. Increasing the number of remanufacturing cycles will increase the total cost rather than the number of manufacturing cycles. This study also strengthens the previous analysis that the remanufacturing cycle influences changes in total costs [6]. For that, companies can create policies to reduce the number of remanufactured cycles as a solution to minimize total inventory costs.

Furthermore, from the calculation results, it is found that increasing back-ordering costs, will increase total costs. This cost is also influenced by the cost of the product that is different between manufactured products and remanufactured products. This has also been examined in previous studies, and indirectly the cost of a reorder will be directly proportional to the total cost [6]. For that, the company can create policies regarding the backorder cost as well as backorder levels to minimize the expense of inventory costs. The cost effect of BCp and BCr can be seen in Figure 10 and Figure 11.

In the previous discussion about the impact of returns on products obtained in Table 6 and Table 7, the rate of product return was not too significant in changing total costs. However, the real change in storage costs is quite significant. What is interesting is that at the time of zero product returns manufacturing companies cannot carry out remanufacturing. Returns on manufactured products must be greater than remanufactured products because these remanufactured products will be used up more quickly by their useful life. Companies can create policies to maximize product returns so that demand can be met. Either by collecting products, or hiring collectors or third-parties as parties who can

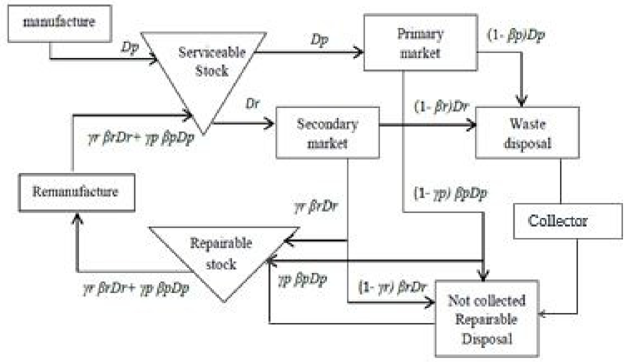

FIGURE 12. Material flow by adding collectors.

maximize product returns to the company to be reproduced. Third parties who participate in collecting the returned products used in the remanufacturing process [40]. Remanufacturing has the opportunity to reduce costs through process innovation, where the opportunity is used in the supply chain consisting of producers and retailers to coordinate cost expenditures [41]. Regarding the policy of adding third parties such as retailers or collectors, this can then be considered by the company. Explanation of this as can be illustrated in Fig. 12.

Products from remanufacturing are considered by consumers to have quality below the new product. This is also explained in the research that has been conducted by Jaber and El Saadany [5]. In their research, it was found that the consumers' perceptions resulted in a lost sales situation where there was a period of out of stock for goods produced and goods that were reproduced [5]. Inventory is possible with a backorder marked with an order receipt from the customer will still be accepted even at the time when there is no inventory [6]. By using a third-party inventory managed by the company itself is expected to be able to reduce waste and use of natural resources as raw materials. Also, the company can produce products with almost the same quality as new products because it can choose and know the consumables that will be processed back into remanufacturing products.

Some previous studies that discussed the effect of variables on costs incurred by the company [1], Beemsterboer *et al.* [42]. Their research shows that storage capacity affects storage costs and total costs, as well as policies regarding ordering decisions. These results are in line with this research that storage capacity affects the increase and decrease in storage costs, and influences decisions that companies must make. Furthermore, Cárdenas-Barrón [43] in his study showed that the level of backorder affects lot size. In the research developed further in this study shows that the cost of reordering and a high reorder rate will result in increased inventory costs. Companies can consider the backorder rate to minimize total costs, further research can consider the effect of the backorder rate on backorder costs to optimize total costs, as well as provide better policies for the company.

Jamal *et al.* [44] has reviewed two different cycles that affect the optimal level of quantity. In their research conducted several different cycles and found that there are differences in the amount of quantity produced. In this study, it was found that the more the number of cycles, the greater the total costs incurred, slightly different from previous studies that consider two cycles at once. Future studies can make direct comparisons of two different cycles to determine the minimum total cost and optimal quantity. Research by Alinovi *et al.* [45] show that the adoption of a return policy for audited companies is not profitable compared to existing asset management policies, but at the same time, they find that the return policy can be beneficial for higher economic value assets which lead to a significant reduction of total costs. In this study it was found that the higher the product return rate would minimize the total cost, compared to previous studies there were some differences in decisions that could be taken. So that the product returns policy evaluation conducted by the company should be able to return the remanufactured product into a profit.

V. CONCLUSION

This study developed a model for remanufacturing inventory considering storage capacity. The objective is to find optimal solutions for the remanufactured quantity by minimizing total costs. In this article, a sensitivity analysis was also done to understand the impact of the changes in the variables and constraints involved of the models on the optimal solutions. The capacitated remanufacturing inventory model (CRIM) developed in this article found that the number of cycles (m and n) affected the quantity of remanufacturing proceeded and the total costs. The pattern of the relationship between those three variables is linear, which is the effect of the number of cycles is linear to the quantity and total costs. Moreover, it is also found that the greater the number of cycles, the more quantity remanufactured and the greater the total costs. Unlike the case with backorder costs (BCr and BCp), the higher the backorder costs, the smaller the quantity remanufactured that results in a greater of the total costs. Furthermore, the level of used product collection (γr and γp) is inversely proportional to the quantity remanufactured and the total costs, which is the greater the collection of used products, the smaller the quantity and the total costs. This has an impact on the policies that will be taken by the company.

Further research can consider the number of manufacturing and remanufactured cycles to produce optimal lots as well as reducing reordering costs, and reduce total costs, and may consider product collection by adding Third-party variables as collectors.

REFERENCES

[1] A. Atasu, V. D. R. Guide, Jr., and L. N. Van Wassenhove, "So what if remanufacturing cannibalizes my new product sales?" *California Manage. Rev.*, vol. 52, pp. 56–76, Feb. 2010.

[2] S. C. Bulmuş, S. X. Zhu, and R. Teunter, "Capacity and production decisions under a remanufacturing strategy," *Int. J. Prod. Econ.*, vol. 145, pp. 359–370, Sep. 2013.

[3] Z. Liu, J. Chen, and C. Diallo, "Optimal production and pricing strategies for a remanufacturing firm," *Int. J. Prod. Econ.*, vol. 204, pp. 290–315, Oct. 2018.

[4] K. Richter, "The extended EOQ repair and waste disposal model," *Int. J. Prod. Econ.*, vol. 45, pp. 443–447, Aug. 1996.

[5] M. Y. Jaber and A. M. El Saadany, "The production, remanufacture and waste disposal model with lost sales," *Int. J. Prod. Econ.*, vol. 120, no. 1, pp. 115–124, 2009.

[6] P. Hasanov, M. Y. Jaber, and S. Zolfaghari, "Production, remanufacturing and waste disposal models for the cases of pure and partial backordering," *Appl. Math. Model.*, vol. 36, pp. 5249–5261, Nov. 2012.

[7] J. O. Cunha, H. H. Kramer, and R. A. Melo, "Effective matheuristics for the multi-item capacitated lot-sizing problem with remanufacturing," *Comput. Oper. Res.*, vol. 104, pp. 149–158, Apr. 2019.

[8] Z. Pan, J. Tang, and O. Liu, "Capacitated dynamic lot sizing problems in closed-loop supply chain," *Eur. J. Oper. Res.*, vol. 198, pp. 810–821, Nov. 2009.

[9] A. Roshani, D. Giglio, and M. Paolucci, "A relax-and-fix heuristic approach for the capacitated dynamic lot sizing problem in integrated manufacturing/remanufacturing systems," *IFAC-PapersOnLine*, vol. 50, pp. 9008–9013, Jul. 2017.

[10] S.-P. Jeng, "Increasing customer purchase intention through product return policies: The pivotal impacts of retailer brand familiarity and product categories," *J. Retailing Consum. Services*, vol. 39, pp. 182–189, Nov. 2017.

[11] Z. Pei, A. Paswan, and R. Yan, "E-tailer's return policy, consumer's perception of return policy fairness and purchase intention," *J. Retailing Consum. Services*, vol. 21, pp. 249–257, May 2014.

[12] R. Teunter, "Lot-sizing for inventory systems with product recovery," *Comput. Ind. Eng.*, vol. 46, pp. 431–441, Jun. 2004.

[13] W. L. Ijomah, "Addressing decision making for remanufacturing operations and design-for-remanufacture," *Int. J. Sustain. Eng.*, vol. 2, pp. 91–102, Jun. 2009.

[14] I. Dobos and K. Richter, "A production/recycling model with quality consideration," *Int. J. Prod. Econ.*, vol. 104, pp. 571–579, Dec. 2006.

[15] A. M. A. El Saadany and M. Y. Jaber, "A production/remanufacturing inventory model with price and quality dependant return rate," *Comput. Ind. Eng.*, vol. 58, pp. 352–362, Apr. 2010.

[16] K. Govindan, M. Palaniappan, Q. Zhu, and D. Kannan, "Analysis of third party reverse logistics provider using interpretive structural modeling," *Int. J. Prod. Econ.*, vol. 140, pp. 204–211, Nov. 2012.

[17] T. Maiti and B. C. Giri, "A closed loop supply chain under retail price and product quality dependent demand," *J. Manuf. Syst.*, vol. 37, pp. 624–637, Oct. 2015.

[18] M. Fleischmann, *Quantitative Models for Reverse Logistics* vol. 501. Berlin, Germany: Springer, 2001.

[19] E. Bazan, M. Y. Jaber, and A. M. A. El Saadany, "Carbon emissions and energy effects on manufacturing–remanufacturing inventory models," *Comput. Ind. Eng.*, vol. 88, pp. 307–316, Oct. 2015.

[20] K. Kamigaki, M. Matsumoto, and Y. A. Fatimah, "Remanufacturing and refurbishing in developed and developing countries in Asia—A case study in photocopiers," *Proc. CIRP*, vol. 61, pp. 645–650, Jan. 2017.

[21] S. Minner, "Economic production and remanufacturing lot-sizing under constant demands and returns," in *Operations Research Proceedings*. Berlin, Germany: Springer, 2001, pp. 328–332.

[22] S. Rubio and A. Corominas, "Optimal manufacturing–remanufacturing policies in a lean production environment," *Comput. Ind. Eng.*, vol. 55, pp. 234–242, Aug. 2008.

[23] J. D. Blackburn, V. D. R. Guide, Jr., G. C. Souza, and L. N. Van Wassenhove, "Reverse supply chains for commercial returns," *California Manage. Rev.*, vol. 46, pp. 6–22, Jan. 2004.

[24] D. Waters, *Inventory Control and Management*. Hoboken, NJ, USA: Wiley, 2008.

[25] L. A. San-José, J. Sicilia, and J. García-Laguna, "An economic lot-size model with partial backlogging hinging on waiting time and shortage period," *Appl. Math. Model.*, vol. 31, pp. 2149–2159, Oct. 2007.

[26] I. Konstantaras and S. Papachristos, "Lot-sizing for a single-product recovery system with backorder," *Int. J. Prod. Res.*, vol. 44, no. 10, pp. 2031–2045, 2006.

[27] K. Richter, "The EOQ repair and waste disposal model with variable setup numbers," *Eur. J. Oper. Res.*, vol. 95, pp. 313–324, Dec. 1996.

[28] I. Dobos and K. Richter, "The integer EOQ repair and waste disposal model–further analysis," *Central Eur. J. Oper. Res.*, vol. 8, pp. 173–194, Jan. 2000.

[29] O. Tang and R. W. Grubbström, "Considering stochastic lead times in a manufacturing/remanufacturing system with deterministic demands and returns," *Int. J. Prod. Econ.*, vols. 93–94, pp. 285–300, Jan. 2005.
[30] A. M. A. El Saadany and M. Y. Jaber, "A production/remanufacture model with returns' subassemblies managed differently," *Int. J. Prod. Econ.*, vol. 133, pp. 119–126, Sep. 2011.
[31] S. D. Flapper, J.-P. Gayon, and L. L. Lim, "On the optimal control of manufacturing and remanufacturing activities with a single shared server," *Eur. J. Oper. Res.*, vol. 234, pp. 86–98, Apr. 2014.
[32] H. Liao and Q. Deng, "EES-EOQ model with uncertain acquisition quantity and market demand in dedicated or combined remanufacturing systems," *Appl. Math. Model.*, vol. 64, pp. 135–167, Dec. 2018.
[33] O. A. Kilic and H. Tunc, "Heuristics for the stochastic economic lot sizing problem with remanufacturing under backordering costs," *Eur. J. Oper. Res.*, vol. 276, no. 3, pp. 880–892, 2019.
[34] R. H. Teunter, Z. P. Bayindir, and W. Van Den Heuvel, "Dynamic lot sizing with product returns and remanufacturing," *Int. J. Prod. Res.*, vol. 44, no. 20, pp. 4377–4400, 2006.
[35] P. Piñeyro and O. Viera, "The economic lot-sizing problem with remanufacturing and one-way substitution," *Int. J. Prod. Econ.*, vol. 124, pp. 482–488, Apr. 2010.
[36] N. Wang, Z. He, J. Sun, H. Xie, and W. Shi, "A single-item uncapacitated lot-sizing problem with remanufacturing and outsourcing," *Procedia Eng.*, vol. 15, pp. 5170–5178, 2011.
[37] J. O. Cunha, I. Konstantaras, R. A. Melo, and A. Sifaleras, "On multi-item economic lot-sizing with remanufacturing and uncapacitated production," *Appl. Math. Model.*, vol. 50, pp. 772–780, Oct. 2017.
[38] S. E. Marshall and T. W. Archibald, "Lot-sizing for a product recovery system with quality-dependent recovery channels," *Comput. Ind. Eng.*, vol. 123, pp. 134–147, Sep. 2018.
[39] S. A. S. Ali, M. Doostmohammadi, K. Akartunalı, and R. van der Meer, "A theoretical and computational analysis of lot-sizing in remanufacturing with separate setups," *Int. J. Prod. Econ.*, vol. 203, pp. 276–285, Sep. 2018.
[40] S.-L. Chung, H.-M. Wee, and P.-C. Yang, "Optimal policy for a closed-loop supply chain inventory system with remanufacturing," *Math. Comput. Model.*, vol. 48, pp. 867–881, Sep. 2008.
[41] M. Reimann, Y. Xiong, and Y. Zhou, "Managing a closed-loop supply chain with process innovation for remanufacturing," *Eur. J. Oper. Res.*, vol. 276, pp. 510–518, Jul. 2019.
[42] B. Beemsterboer, R. Teunter, and J. Riezebos, "Two-product storage-capacitated inventory systems: A technical note," *Int. J. Prod. Econ.*, vol. 176, pp. 92–97, Jun. 2016.
[43] L. E. Cárdenas-Barrón, "An easy method to derive EOQ and EPQ inventory models with backorders," *Comput. Math. Appl.*, vol. 59, pp. 948–952, Jan. 2010.
[44] A. M. M. Jamal, B. R. Sarker, and S. Mondal, "Optimal manufacturing batch size with rework process at a single-stage production system," *Comput. Ind. Eng.*, vol. 47, pp. 77–89, Aug. 2004.
[45] A. Alinovi, E. Bottani, and R. Montanari, "Reverse logistics: A stochastic EOQ-based inventory control model for mixed manufacturing/remanufacturing systems with return policies," *Int. J. Prod. Res.*, vol. 50, no. 2, pp. 1243–1264, 2012.

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